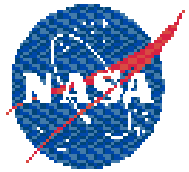


Human Factors
research and technology

Prospective Memory and Concurrent Task Performance

Key Dismukes

Human Factors Research and Technology Division

20 October 2004


LOS ANGELES CITY
FIRE DEPARTMENT
180
USAIR

Operational Consequences of Memory Lapses

- **Detroit (1987): DC-9 crashed shortly after take-off**
  - Crew failed to set flaps/slats to take-off position
- **Dallas (1988): B-727 crashed shortly after take-off**
  - Crew failed to set flaps/slats to take-off position
- **Los Angeles (1991): B-737 cleared to land on runway occupied by Metroliner**
  - Controller forgot to release Metroliner to take-off after series of delays
- **La Guardia (1994): MD-82 ran off runway end after high-speed rejected take-off**
  - Crew failed to turn on pitot heat
- **Houston (1996): DC-9 landed gear up**
  - Crew failed to set hydraulic boost pump to high position

Why?

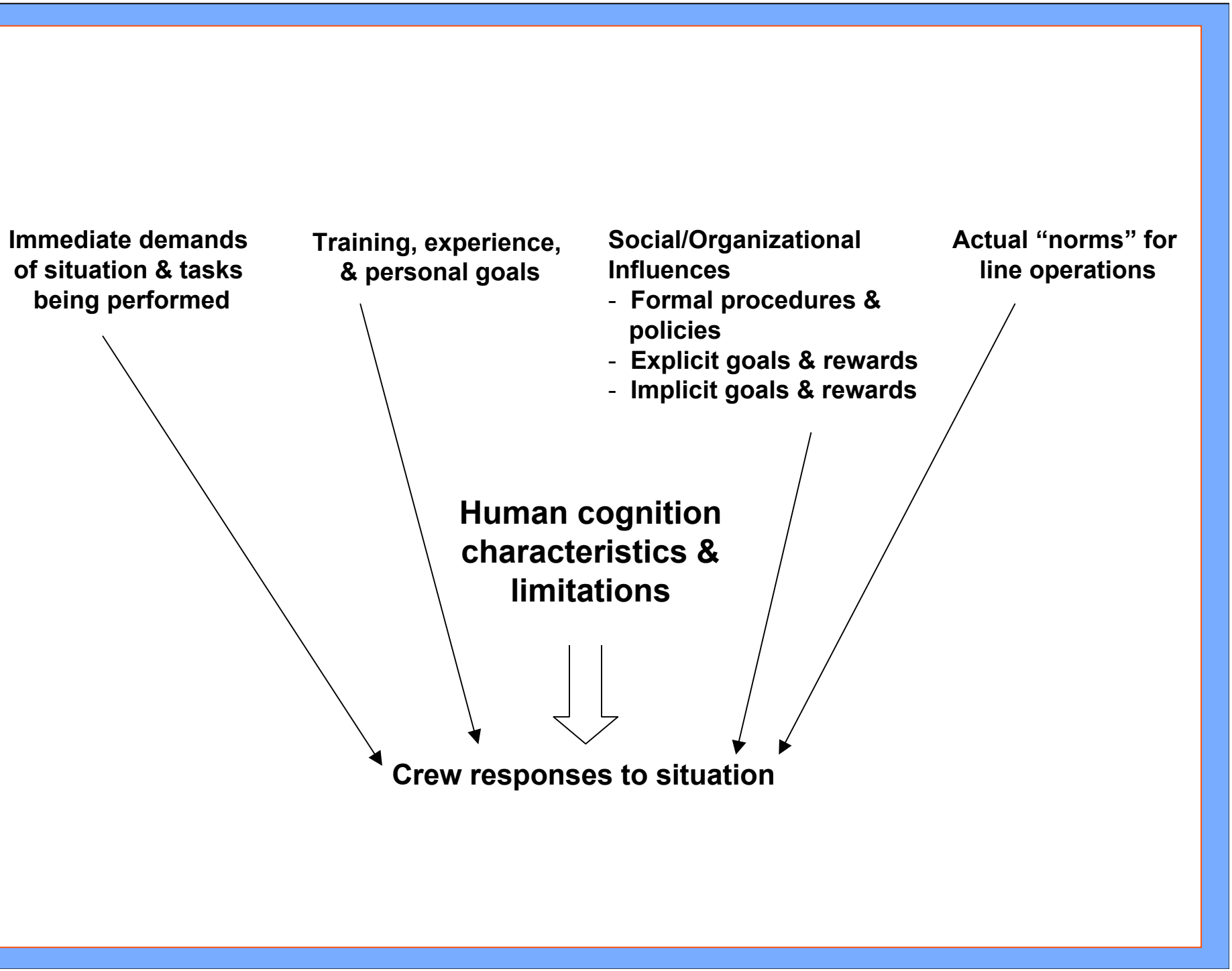
- **Why would highly experienced crews forget a procedural step they normally perform day in and day out?**
- **An ongoing NASA research project**
  - Focuses on airline crews but applicable to all domains of skilled performance (e.g., medicine).
  - Could be extended to space operations.
- **Prospective memory only recently studied in depth by cognitive psychologists.**

Our Research Team

- Sean Belcher
- Ben Berman
- Kurt Colvin
- Key Dismukes
- Rahul Dodhia
- Jon Holbrook
- Kim Jobe
- Loukia Loukopoulos
- Tri Le
- Jessica Lang Nowinski

Most Airline Accidents Attributed to Crew Error

- **What does this mean?**
- **Society: error = blame**
  - Misrepresents nature of cognitive skill.
  - Undercuts safety.
- **Skill/conscientiousness/vigilance necessary but not sufficient.**
- **Error is probabilistic, not deterministic.**


Immediate demands of situation & tasks being performed
Training, experience, & personal goals
Social/Organizational Influences
- Formal procedures & policies
- Explicit goals & rewards
- Implicit goals & rewards
Actual "norms" for line operations
Human cognition characteristics & limitations
Crew responses to situation

Multi-prong Research Approach

- Jumpseat observations to assess operating environment and task demands.
- Analysis of procedures in operating manuals.
- Analysis of NTSB and ASRS reports to identify error types and context.
- Flight simulation with eye-tracking to study expert performance.
- Laboratory studies to investigate underlying cognitive processes.
- Theoretical framework to integrate and interpret data.

Forgetting to Perform Normal Procedural Steps

(Loukopoulos, Dismukes, & Barshi, 2003)

- **Most likely when:**
  - Interrupted
  - Forced to perform habitual action out of normal sequence
  - Normal environmental cues are absent
  - Must try to remember to perform non-habitual actions at later time
  - Required to juggle several tasks concurrently
- **Situations have diverse surface features but share underlying cognitive features.**

Interruptions

(Loukopoulos, Dismukes, & Barshi, 2003)

- **Most frequent during pre-start preparations.**
- **Last from seconds to minutes and often require full attention.**
- **“Garden Path”: Series of other attention-demanding tasks follow the interruption.**
- **Pilots forget to go back to interrupted task.**

Interruption Example:

ASRS Report # 437750

"We were on descent, preparing to accomplish final items on the approach checklist… while being vectored for visual approach… [Controller] instructed to proceed to the final approach fix, descend to 2500 feet, and look for traffic… [Controller] advised we had high overtake speed on traffic… Accomplished all these instructions and began to slow and configure aircraft for landing…"

Outcome: Crew landed without completing checklist and failed to notify flight attendants landing was imminent.

Habitual Actions Performed Out of Normal Sequence

Example: slush on taxiway forces crew to defer setting flaps (normally set before taxi).

Summary of ASRS report #263589

> *Crew deferred setting flaps for takeoff because of snow accumulation on taxiways. Once in line for takeoff they became busy discussing a problem they had encountered earlier with the aircraft's auxiliary power unit. A sudden and unexpected instruction from Tower placing them next for takeoff triggered the crew to rush to complete a wing contamination inspection and the Below-the-line part of the checklist, inadvertently omitting the Down-to-the-line items and thus not setting flaps.*

Outcome: Configuration warning system alerted crew on takeoff roll. Takeoff aborted.

Hypothesis: Absence of normal cues from (1) environment and (2) preceding actions removes triggers for memory retrieval.

Juggling Concurrent Tasks

- **Each pilot of crew often required to manage several tasks concurrently.**

  Summary of ASRS report #414686

  During taxi a first officer discovered that earlier calculations of performance data for the planned takeoff runway had been based on the wrong flap setting. In the course of rechecking if the aircraft would be too heavy for takeoff from the particular runway, he failed to adequately monitor the captain, who taxied past the hold short line.

- **Outcome: Runway incursion.**

Concurrent Task Characteristics

- **Traditional lab paradigms fail to capture central characteristics of cockpit concurrent tasks.**

Typical lab paradigm	Cockpit
– Frequent attention switching between tasks	– Sustained attention to foreground task
– Salient cueing for both tasks	– Periodic checking of states of other tasks
	– Cues for other task are not conspicuous

Hypothesis:

- **Lapses in monitoring occur when pilots become absorbed in foreground task -- monitoring task slips from working memory and lacks cues for retrieval.**

Prospective Memory (PM)

- **Remembering to perform an action that must be delayed.**
- **Relatively new field of human memory research.**
- **Defining characteristics:**
  - Delay between forming intention and opportunity to execute (seconds to years).
  - Delay filled with other tasks that occupy attention.
  - No explicit prompt telling us it is time to execute intention.
- **So how do we ever remember to perform intentions?**
  - A theoretical perspective

Background for Prospective Memory Theory

Draws heavily on:

- Cowan: theoretical framework for attention and memory.
- Anderson et. al: ACT-R cognitive architecture.

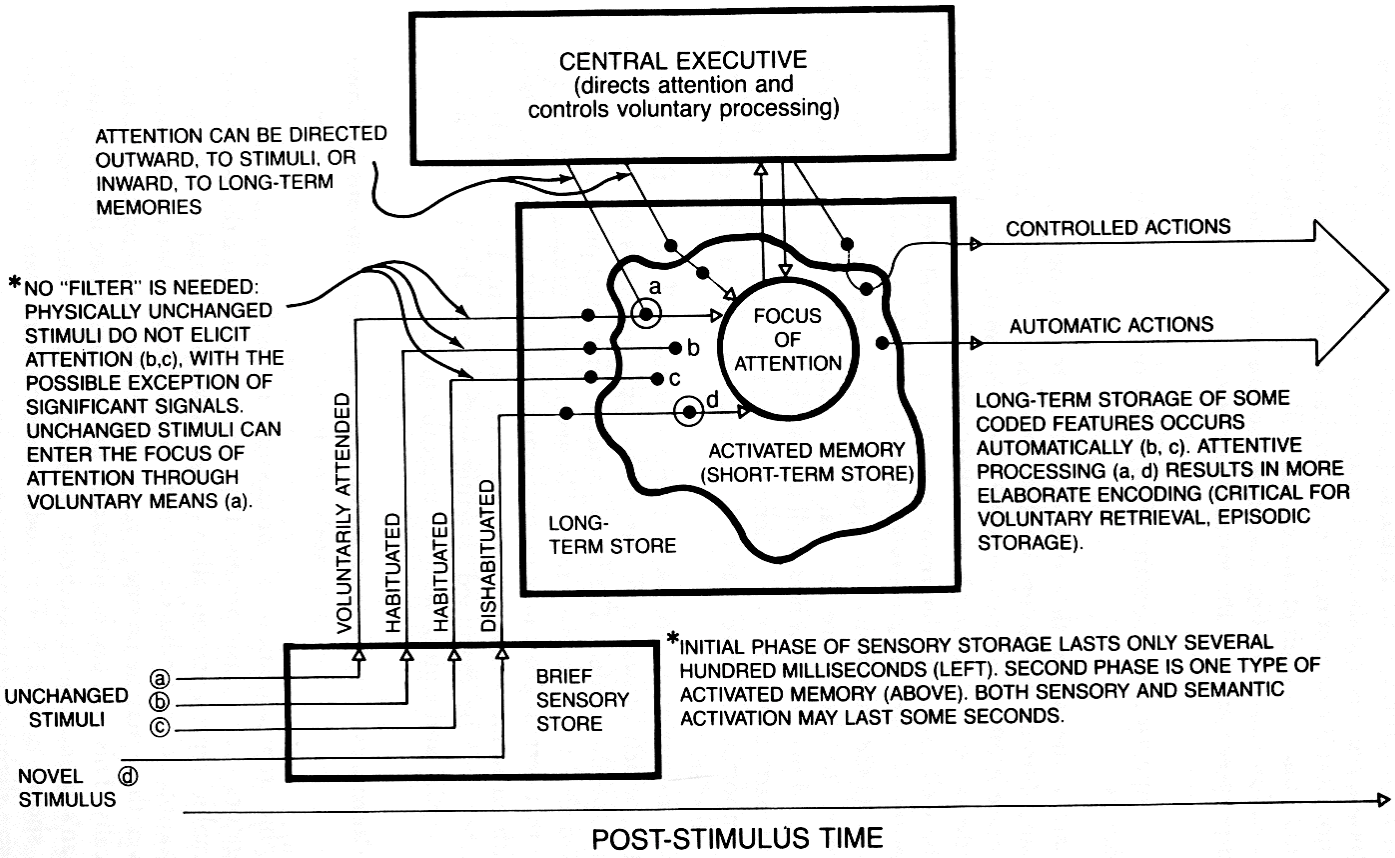


Fig. 1.5 A basic model of information processing. (From N. Cowan, Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104,* p. 180, Fig. 1. Copyright © 1988 by the American Psychological Association. Reprinted by permission.)

Background

- **Content of focal attention (FA) corresponds to conscious awareness.**
  - Attention is limited resource (very narrow bandwidth).
- **Long-term memory (LTM) is vast store.**
  - Contains declarative knowledge, procedural skills, and episodic experience.
  - Items stored in networks of associated components and related items.
- **Memory items have varying degrees of "activation" (ACT-R)**

  $A(i)_{total} = A(i)_{baseline} + A(i)_{source}$

  - $A(i)_{baseline}$ is relatively stable, determined largely by how often it is used.
  - $A(i)_{source}$ derives from current contents of FA, spreads to all LTM items with which associated.
  - $A(i)_{source}$ proportional to strength of association and inversely proportional to number of other items associated to use (fan effect).

Theoretical Framework for Prospective Memory

(Nowinski and Dismukes, in preparation)

- **Encoding: set goal of performing task at later time.**
  - Intention represented as IF…THEN statement.
  - Time and conditions for execution may or may not be well-defined.
- **Retention: turn attention to series of ongoing tasks.**
  - Deferred intention moves out of FA but is retained in LTM.
- **Retrieval: individual notices environment cue, or ongoing task generates cue previously associated with deferred intention.**

Theoretical Framework for Prospective Memory

- **Retrieval (continued):**
  - Cue spreads activation to all associated items in LTM, including deferred intention.
  - Activation received by intention:
    - Proportional to strength of association with cue.
    - Inversely proportional to path length and number of other items associated with cue.
  - Activation from multiple cues is summated.
  - Activation decays rapidly when cue is removed from FA.
  - Activation summed from current and previous cues (contributions of previous cues limited by decay).
- $P(i)_{retrieval} = k_B A(i)_{baseline} + k_S \sum_{t=0}^{T} \sum_{c=0}^{N} A(i)_{source}$

Implications of Model

- **Retrieval of intention must compete with retrieval of memory items associated with and supported by ongoing task.**
- **Importance of deferred task does not directly affect probability of retrieval.**
  - Even if life-or-death task
  - Can compensate by adopting strategy if recognize vulnerability

Predictions of Theory

- **Accounts for data from wide range of studies, e.g.:**
  - PM improves with strength of association between cue and intention.
  - Uncommon cues more effective than common cues (fan effect).
  - PM improves with degree of similarity between cue and "IF" component.
  - Distinctive cues more effective than non-distinctive cues.
  - Reducing attention to cues impairs PM.
  - Context providing additional cues improves PM.
- **PM performance largely driven by the extent to which ongoing tasks direct attention toward or away from relevant cues.**
  - Existing lab paradigms fail to explore.
  - Holbrook analysis of real-world PM situations.
- **Formulations/encoding of conditions for execution of intentions should affect performance substantially.**
  - Holbrook analysis
  - Dodhia experiments

An Everyday Illustration

Intention: Pick up laundry after work.

- **Intention not maintained continuously in attention through day.**
- **Ongoing tasks/activities may lead to thoughts and encounters with cues associated with intention, e.g.:**
  - Act of leaving work
  - Putting on coat (a clothing article)
  - Stain on coat
- **Haphazard basis for retrieval.**
  - Cues must be noticed at time appropriate for retrieval.
- **Importance of goal does not effect probability of retrieval!**

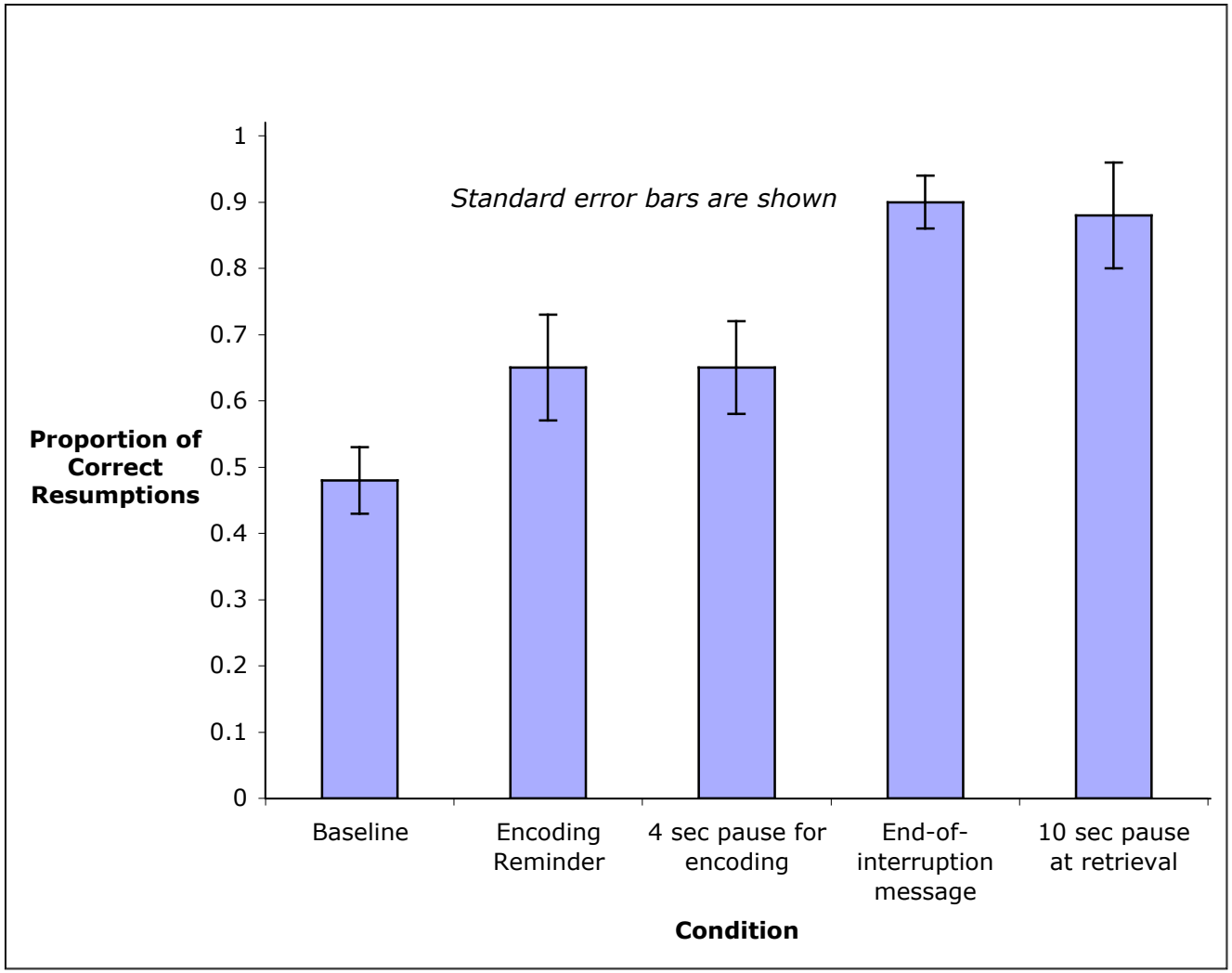
Theoretical Model Suggest Ways to Improve Performance

- **Create conspicuous cues we are likely to encounter when intention is to be retrieved.**
  - E.g., place library books to be returned against exit door.
- **Encode specific information about environment to be encountered when intention is to be retrieved.**
  - Associate environmental cues with intention.
- **Writing notes combines both techniques.**
  - But note must be placed so will be encountered at time retrieval required.

Interruptions: A Special Case of Prospective Memory

- **Interruptions create implicit goal of resuming interrupted task later.**
  - Interruptions are typically sudden and attention-demanding.
  - Hypothesized that individuals may not encode an explicit intention (goal is only implicit in general schema for tasks).
- **Experimental paradigm created by Rahul Dodhia.**
  - Participants take series of written quizzes resembling SAT.
  - Occasionally a quiz is interrupted by another task after which computer goes to next set of quizzes.
  - Participant must remember to return to interrupted quiz before continuing series.

Interruption Experiments



Ways Airlines and Pilots Can Reduce Vulnerabilities to PM Errors

- **Analyze actual line ops ⟶ write procedures to minimize opportunities for disruptions.**
- **Analyze actual fleet "norms" for how checklists are executed.**
  - Danger of pilots "looking without seeing".
- **Develop explicit guidance for monitoring.**
  - Each pilot should cross-check actions of other pilot for "killer" items.
- **When interrupted or deferring a task:**
  - Pause to encode intentions to resume.
  - Create conspicuous cue as reminder.
- **Develop habit of deliberately pacing procedures and checklists to allow attentive supervision of habitual response.**
  - Avoid rushing.
- **Pause at critical junctures to review that all has been accomplished before proceeding.**

Principles for Transition of Research Projects

- **To conduct relevant research scientists must:**
  - Develop expertise in operational domain.
  - Study expert performance in real-world settings.
  - Use this knowledge to guide lab experiments and theories.
- **Airlines are constrained by razor-thin profit margins.**
  - No personnel to translate research findings.
  - Eager to collaborate with NASA to implement useful products.
- **Cannot wait 5-10 years until research projects are completed.**
  - Operational decisions made daily, require best judgment.
  - Ethical dilemma: Should we present findings not fully validated? Qualify limits of certainty to customers.
  - Provide annual updates (fits training cycle).

"Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity, or neglect." - Unknown

For further information:

http://human-factors.arc.nasa.gov/ihs/flightcognition/